't Hooft anomaly of charge-q Schwinger model on the lattice in Hamiltonian formalism

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't Hooft anomaly of charge-q Schwinger model in the Hamiltonian formalism

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Motivation

- New 't Hooft anomalies have been found in recent studies.
  - It is based on Euclidean path integral.

$\Rightarrow$ What about the Hamiltonian formalism?

This is the basic setup in quantum simulators.

- Toy example: charge-q Schwinger model
  - $\mathbb{Z}_q$ 1-form symmetry $\times$ $\mathbb{Z}_{2q}$ chiral symmetry as $m_\varphi \to 0$.
  - Anomaly matching claims $(\mathbb{Z}_{2q})_\chi \xrightarrow{SSB} (\mathbb{Z}_2)_F$.
  - This is exactly solved.

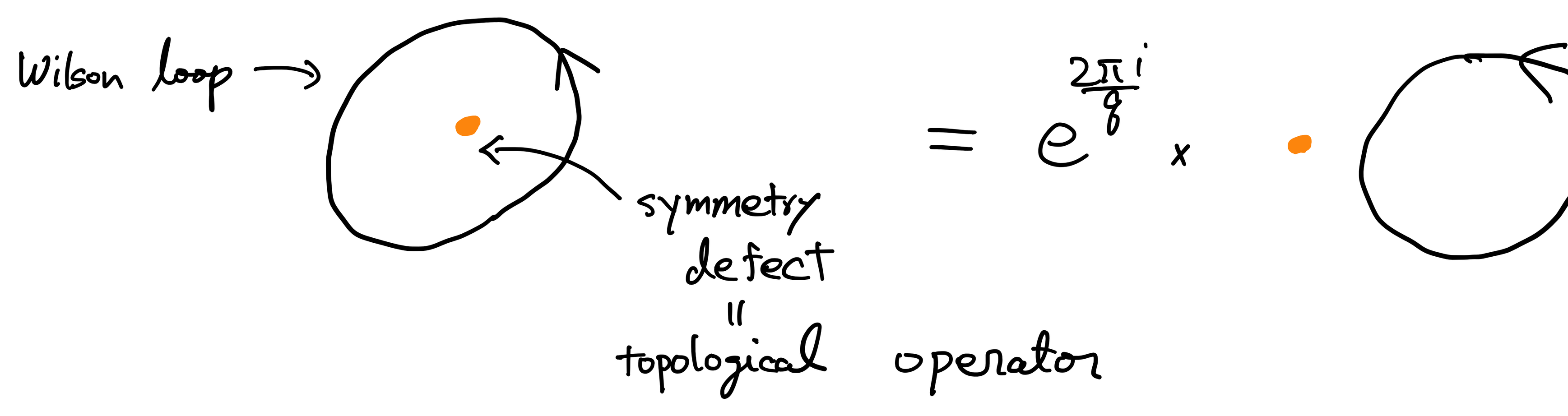
Charge-q Schwinger model

$$\mathcal{L} = \bar\Psi \gamma^\mu (\partial_\mu + i q a_\mu)\Psi + m\bar\Psi\Psi + \frac{1}{g^2} da \wedge * da + i\frac{\theta}{2\pi} da.$$

q: some integer ≥ 1.

This model has $\mathbb{Z}_q$ 1-form symmetry

$$W(C) = e^{i\oint_C a} \mapsto e^{\frac{2\pi i}{q}} W(C).$$



Chiral symmetry & mixed 't Hooft anomaly

Under the chiral transformation

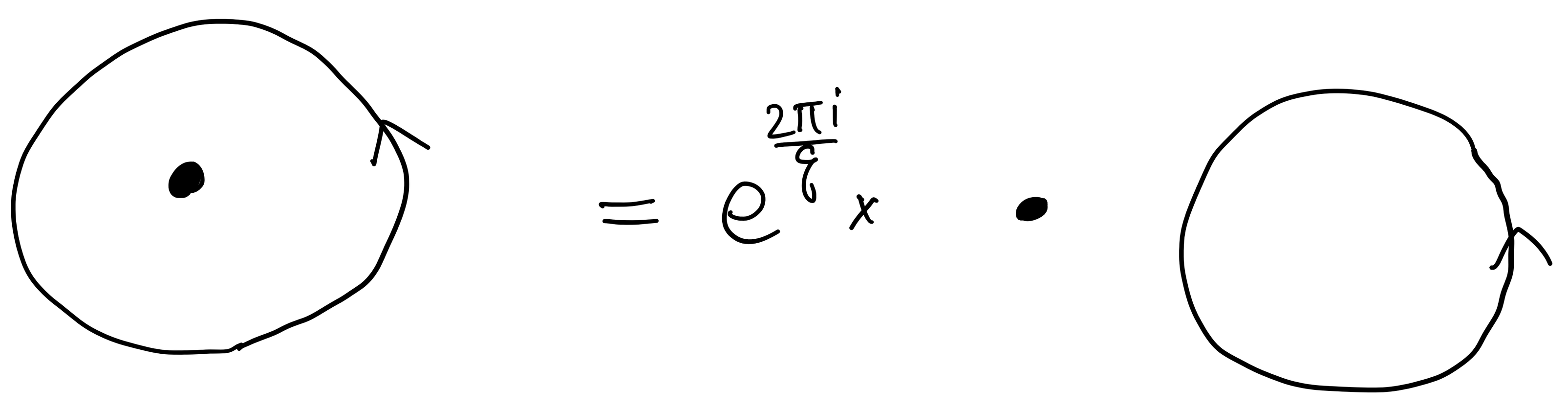
$$\psi \to e^{i\alpha\gamma_3}\psi, \quad \bar\Psi \to \bar\Psi e^{i\alpha\gamma_3}$$

the θ-term is shifted:

$$\theta \to \theta + 2\alpha \times q.$$

If $q > 1$ w/ $m = 0$, there is a nontrivial chiral sym: $(\mathbb{Z}_{2q})$ chiral.

Anomaly $\bullet \approx \bar\Psi\psi$ (chiral operator)



$\Rightarrow$ In $m \to 0$, Wilson loop $\approx$ Chiral symmetry generator.

Hamiltonian formalism

$$H = \frac{g^2}{2}\left(\Pi(x) - \frac{\theta}{2\pi}\right)^2 - \bar\Psi i\gamma^1(\partial_1 + i q a_1)\psi + m\bar\Psi\psi$$

$\uparrow$ conjugate momentum of $a_1(x)$.

Gauss law:

$$\partial_1 \Pi = q\bar\Psi\gamma^0\psi$$

$\mathbb{Z}_q$ 1-form symmetry

- Symmetry generator $U(x) = \exp\left(\frac{2\pi i}{q}\Pi(x)\right)$.

(*) $T(x) = U(x)^q$ is the large gauge transformation

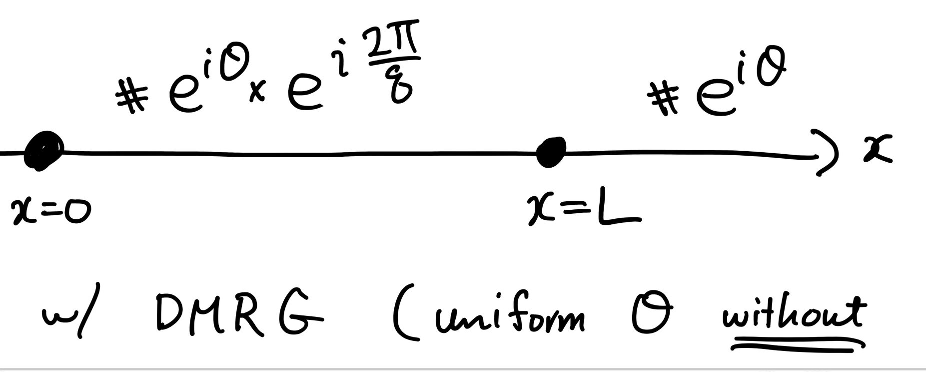
$$\Rightarrow U(x)^q |\text{phys}\rangle = |\text{phys}\rangle$$

- Wilson loop = modification of the Gauss law

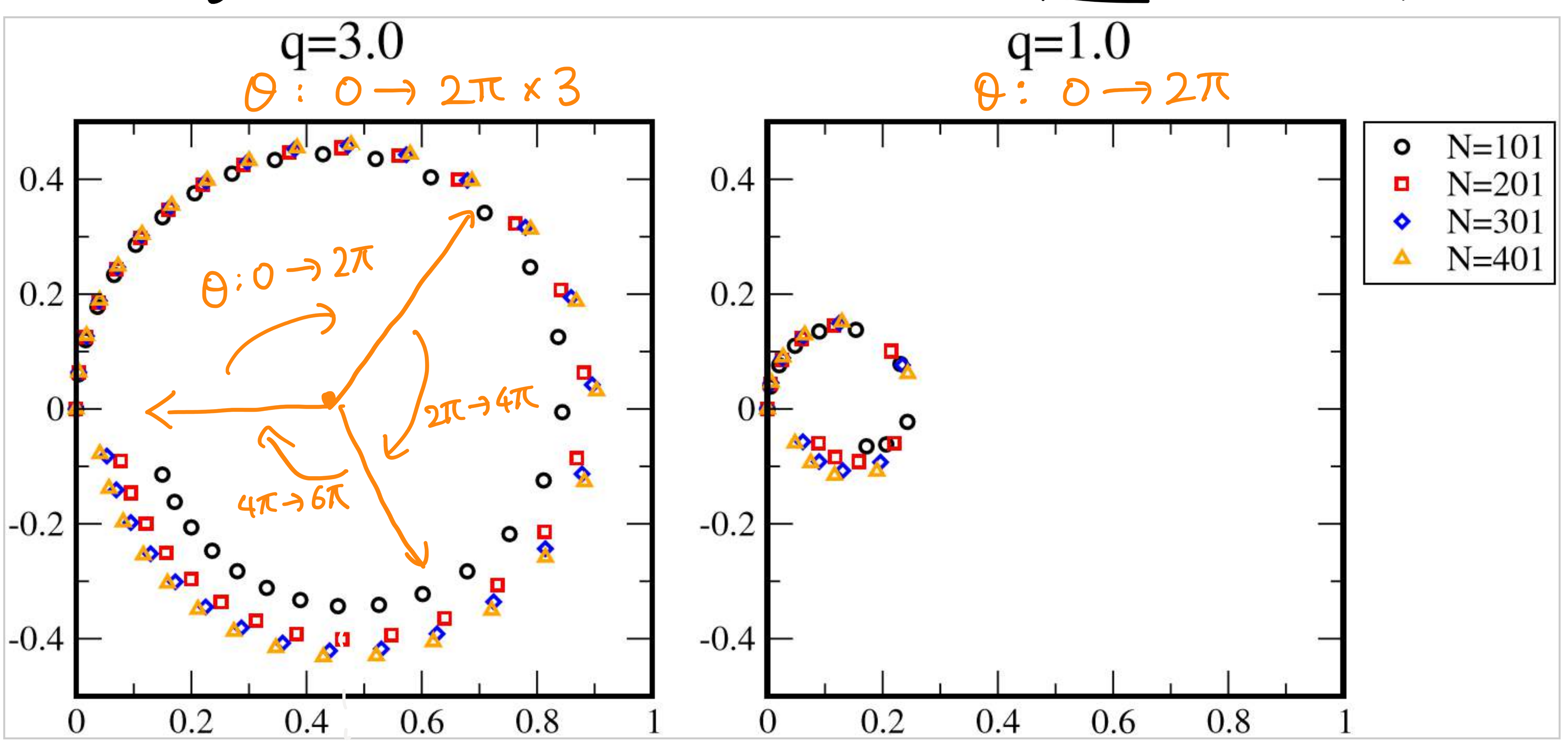
$$\partial_1 \Pi = q\bar\Psi\gamma^0\psi + n(\delta(x-L) - \delta(x))$$

Expectation from Anomaly & Preliminary Results

$\langle$chiral op$\rangle = \# e^{i\theta}$ $\quad$ $\# e^{i\theta} \times e^{i\frac{2\pi}{q}}$ $\quad$ $\# e^{i\theta}$ $\quad$ $\left(\text{when } \frac{m}{g} \to 0\right)$



(Preliminary result w/ DMRG (uniform θ without Wilson loop insertions))



Summary

- Charge-q Schwinger model has $\mathbb{Z}_q^{[1]} \times (\mathbb{Z}_{2q})_\chi$ in $m \to 0$. with mixed 't Hooft anomaly.
- This feature has been understood using Euclidean path integral.
- We reinterpret some of these in Hamiltonian formalism.